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## SYSTEM AND METHOD FOR IMPROVING THE MOVEMENT AND DISCHARGE OF MATERIAL FROM VESSELS

### REFERENCE TO RELATED APPLICATIONS

**[0001]** This application draws priority from U.S. Provisional Patent application 60/309,332 filed on August 2, 2001 (attorney ref. 2065.005 P). The disclosure of this Provisional Patent Application is incorporated by reference herein in its entirety.

### TECHNICAL FIELD

**[0002]** This invention relates generally to systems and methods for improving the movement of solid materials in vessels and the discharge of solid materials from vessels. Specifically, the present invention provides systems and methods for improving the movement and discharge of comminuted cellulosic fibrous material in treatment vessels, for example, in the pulping process.

### BACKGROUND OF THE INVENTION

**[0003]** In many process industries, cylindrical vessels are used to store or treat the materials processed. For example, in the Pulp and Paper Industry, solid materials are handled and treated in assorted vessels. These materials typically include softwood or hardwood chips, recycled papers, and cellulose pulp, among other types of materials. Often, the movement of solid materials in treatment and storage vessels or the discharge of the solid materials from treatment or storage vessels is critical to the effectiveness and efficiency of the process being performed. For example, in vessels where treatment or retention time or uniformity of treatment chemical concentration can affect the quality of the product produced, discontinuous, interrupted, or non-uniform movement or discharge of the material from the vessels can dramatically adversely

effect the quality of the product produced. The adverse effects upon the quality of the product can be the result of either non-uniform flow of material, non-uniform flow of treatment fluids, non-uniform temperature distribution, non-uniform treatment chemical concentrations, or combinations thereof.

**[0004]** For example, in the Chemical Pulping Industry, comminuted fibrous materials, such as softwood or hardwood chips, are treated with treatment chemicals at time, temperature, and pressure. In the processing of wood chips, the non-uniform movement of wood chips and treatment liquids, for example, kraft treatment liquor, can significantly affect the time, temperature, and chemical concentrations at which chips are treated. Specifically, the quality of the pulp produced, for example, the pulp's cooking uniformity, strength characteristics, and brightness, among other things, can be adversely affected by the non-uniform movement of the chips or the treatment liquid during treatment.

**[0005]** Though common to many process and material handling industries, in the Pulping Industry, treatment of wood chips, and other forms of comminuted cellulosic fibrous material, is typically performed in tall cylindrical vessels or reactors, and the like, for example, one typical reactor vessel used in the art is referred to as a "digester". Typically, wood chips are introduced at an inlet at the top of these vessels and as the chips proceed downward, typically under the force of gravity, the chips are treated with cooking chemical, for example, kraft white or black liquor, as liquid streams containing the cooking chemical are introduced and removed from the chips as they proceed downward. Typically, the movement of treatment liquids relative to the wood chips, for example, laterally or vertically between the interstices of the wood chips, is often critical to the uniform distribution of cooking chemical and temperature during the treatment process - a process referred to in the art as "cooking". Non-uniformities in temperature or chemical distribution in the vertical treatment vessel can result in non-uniformly-cooked chips, for example, over-cooked or under-cooked chips, which can

affect the efficiency of the cooking process, for example, the degree of delignification, or the efficient use of cooking chemical, or the quality of the product produced, among other things, or a combination thereof.

**[0006]** In vertical treatment vessels, the uniformity of temperature and chemical distribution are also affected by the compression within the column of material, often referred to as the “chip column”. As the material proceeds through the vessel, typically downward from the inlet to the outlet, the weight of the material and liquid above the material increases wherein the material near the bottom of the vessel is more compressed than the material at the top of the vessel. This compression within the chip column can interfere with movement of treatment liquids in the chip column by, among other things, compressing the chips and reducing the interstitial spaces between chips and thus reducing the pathways for liquid movement. Compression in the chip column further exacerbates non-uniform liquid movement when the material being handled is a flexible or pliable material, such as wood chips, which deform under the force of compression and further limit the size of potential liquid pathways. In downward-flowing treatment vessels, having outlets at the bottom, this compression is highest in the discharge zone of vertical vessels. Thus, there is a need in the art to minimize or reduce non-uniform treatment in vessels due to material compression.

**[0007]** Discharge zones of treatment vessels in the Pulping Industry typically include some form of converging transition, for example, a transition from a vertical vessel wall at one diameter to a centrally-located discharge having a second diameter, smaller than the vessel diameter. This converging transition typically causes the path of material flow to change from an essentially vertical direction to a somewhat horizontal direction. This convergence provides additional material compression which can further limit the flow of treatment liquid though the material. This convergence can also provide an obstruction to the uniform flow of material, which again, can affect the uniformity of treatment of the material. Thus, there is a need in the art to provide

treatment vessels and treatment methods that reduce or minimize non-uniform treatment due to convergent flow in the outlets of treatment vessels.

**[0008]** In vertical cylindrical vessels, the uniformity of the movement of material, for example, from an inlet at the top to an outlet at the bottom, can be significantly affected by the uniformity of the discharge at the bottom of the vertical vessel. Discharge zones in vessels used in the Pulping Industry often include an agitating device, for example, a rotating agitator, to assist in promoting discharge of the material out of the outlet. Since the flow of material out the bottom of a vessel can affect the movement of the material above the outlet of the vessel, a non-uniform discharge of material out the bottom of the vessel can interfere with the desired uniform movement and treatment in the vessel above. Thus, there is also a need in the art to provide systems and methods for improving the uniformity of discharge of solid material from vessels.

## SUMMARY OF THE INVENTION

**[0009]** The present invention provides methods and systems which address many of the limitations of the prior art methods and systems. One aspect of the invention is a system for improving the movement of solid material in a cylindrical vessel, the vessel having an inlet, an outlet, a cylindrical portion having an outer dimension, and a converging transition between the cylindrical portion and the outlet, the system comprising means for introducing at least some liquid to the converging transition at a location having a diameter greater than about 75% of the outer dimension of the cylindrical portion of the vessel. In one aspect of the invention, the means for introducing at least some liquid to the converging transition has a diameter greater than about 90 % of the outer dimension of the cylindrical portion of the vessel. In another aspect of the invention, the means for introducing at least some liquid comprises at least one nozzle, for example, a plurality of evenly-spaced nozzles.

According to another aspect of the invention, the vessel further comprises at least one set of dilution nozzles evenly-spaced about the outlet at a first diameter, and wherein the means for introducing at least some liquid to the converging transition is positioned at a second diameter greater than the first diameter. In another aspect of the invention, the vessel further comprises at least one baffle plate (also known as a "slide plate") positioned in the converging transition, and wherein the means for introducing at least some liquid to the converging transition is positioned between the at least one baffle plate and the outlet.

[0010] Another aspect of the invention is a method of treating particulate material in a cylindrical vessel having an interior, an inlet into which particulate material is introduced, and an outlet from which particulate material is discharged, the method comprising: causing the particulate material to flow in the vessel interior in a substantially vertical flow path; causing at least some of the particulate material to flow in a non-vertical flow path toward the outlet by providing a converging transition to the outlet; and introducing a liquid to the converging transition to reduce the resistance to flow of the particulate material through the converging transition to the outlet. In one aspect of the invention, the vessel comprises a vessel having an outer dimension and wherein introducing a liquid to the converging transition comprises introducing a liquid to the converging transition at a location having a diameter greater than about 75% of the outer dimension of the vessel, or greater than about 90% of the outer dimension of the vessel. In one aspect of the invention, providing a converging transition comprises providing a conical transition having a first diameter and a second diameter smaller than the first diameter. In another aspect of the invention, introducing a liquid to the converging transition comprises introducing a liquid to the vicinity of the second diameter of the conical transition. Another aspect of the invention further comprises forming a zone of compression in the converging transition wherein the particulate material is compressed and resistance to flow is increased. In one aspect of the invention, introducing a liquid to the converging transition comprises introducing a

liquid to the zone of compression.

**[0011]** Another aspect of the present invention is a digester for treating comminuted cellulosic fibrous material, the digester comprising: an inlet for introducing comminuted cellulosic fibrous material; a circular cylindrical portion having an outer diameter; an outlet for discharging treated comminuted cellulosic fibrous material; a converging transition between the circular cylindrical portion and the outlet; and means for introducing at least some liquid to the converging transition at a location having a diameter greater than about 75% of the outer diameter of the circular cylindrical portion of the digester. In one aspect of the invention, the means for introducing at least some liquid to the converging transition has a diameter greater than about 90 % of the outer diameter of the circular cylindrical portion of the digester. In one aspect of the invention, the means for introducing at least some liquid comprises a plurality of evenly-spaced nozzles. In another aspect of the invention, the digester further comprises at least one set of dilution nozzles evenly-spaced about the outlet at a first diameter, and wherein the means for introducing at least some liquid to the converging transition is positioned at a second diameter greater than the first diameter. In another aspect of the invention, the digester further comprises at least one baffle plate positioned in the converging transition, and wherein the means for introducing at least some liquid to the converging transition is positioned between the at least one baffle plate and the outlet.

**[0012]** Another aspect of the invention is a method of treating comminuted cellulosic fibrous material in a digester, the digester having an interior, an inlet for introducing comminuted cellulosic fibrous material, and an outlet for discharging treated comminuted cellulosic fibrous material, the method comprising: causing the comminuted cellulosic fibrous material to flow in the digester interior in a substantially vertical flow path; causing at least some of the comminuted cellulosic fibrous material

to flow in a non-vertical flow path toward the outlet by providing a converging transition to the outlet; and introducing a liquid to the converging transition to reduce the resistance to flow of the comminuted cellulosic fibrous material through the converging transition to the outlet. In one aspect of the invention, the digester comprises a vessel having an outer diameter and wherein introducing a liquid to the converging transition comprises introducing a liquid to the converging transition at a location having a diameter which is greater than about 75% of the outer diameter of the vessel. In another aspect of the invention, introducing a liquid to the converging transition comprises introducing a liquid to the converging transition at a location having a diameter which is greater than about 90% of the outer diameter of the vessel. In another aspect of the invention, providing a converging transition comprises providing a conical transition having a first diameter and a second diameter smaller than the first diameter. In another aspect of the invention, introducing a liquid to the converging transition comprises introducing a liquid to a plurality of nozzles positioned in the converging transition. Another aspect of the invention further comprises forming a zone of compression in the converging transition wherein the comminuted cellulosic fibrous material is compressed and resistance to flow is increased. In one aspect of the invention, introducing a liquid to the converging transition comprises introducing a liquid to the zone of compression.

**[0013]** These and other embodiments and aspects of the present invention will become more apparent upon review of the attached drawings, description below, and attached claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The

invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following detailed descriptions of the preferred embodiments and the accompanying drawings in which:

FIGURE 1 is an elevation view in cross-section of a comminuted fibrous material treatment vessel according to the prior art.

FIGURE 2 is an elevation view of the bottom section of a comminuted fibrous material treatment vessel similar to the view shown in FIGURE 1 but illustrating one aspect of the present invention.

FIGURE 3 is a detailed view of one aspect of the invention shown in FIGURE 2.

#### **DETAILED DESCRIPTION OF SOME ASPECTS OF THE INVENTION**

**[0015]** FIGURE 1 illustrates a cross-sectional view of two representative portions of a cylindrical treatment vessel 10, for example, a cylindrical pulping vessel, or digester, typically used in the Pulping Industry. In particular, vessel 10 of FIGURE 1 illustrates a typical continuous chemical pulping digester, that is, a treatment vessel which operates essentially continuously with wood chips continuously introduced at the top and pulp discharged at the bottom. FIGURE 1 illustrates the upper section 12 having an inlet 14 and an upper head 15 and a bottom section 16 having a bottom head 17 and a discharge 18. Vessel 10 typically includes a cylindrical section 19 between the upper head 15 and the bottom head 17. The diameter of cylindrical section 19 may typically vary, for example, the diameter of section 19 may increase in a step-wise fashion along the length of vessel 10.

**[0016]** According to conventional practice, a slurry of comminuted fibrous

material 20, for example, a slurry of wood chips in treatment chemical, is typically introduced to inlet 14 and passes downward in vessel 10 as indicated by arrows 22. The treatment in vessel 10 may be under temperature and pressure, for example, at a temperature over 100 degrees C (212 degrees F) and at a pressure greater than 5 bar (72.5 psig). The treatment time in vessel 10 may range from 1 to 6 hours and will typically dictate the height of vessel 10. Typically, prior art treatment vessels may range from 50 feet in height to over 250 feet in height depending upon the desired treatment time and production rate. The production rate desired also typically dictates the maximum diameter of vessel 10, which may range from about 12 feet to about 35 feet.

**[0017]** In a typical prior art treatment vessel 10, after being introduced to inlet section 12 and passing through and being treated in cylindrical section 19, the slurry of comminuted fibrous material enters the bottom section 16 as indicated by arrows 24. The slurry may be further treated with treatment liquid, as indicated, for example, by arrows 26, and the slurry is ultimately discharged out of outlet 18. The discharge of treated material out of outlet 18 is typically aided by a rotating discharge device 28. One typical discharge device includes a central deflection cone 30 and two or more agitating arms 32 having paddles 34, though other types of discharge devices may be used. Discharge device 28 is typically driven by a drive train, for example, an electric motor and gear box, not shown.

**[0018]** As is typical in the art, the discharge of treated material may be aided by the addition of dilution liquid, in particular, cooling dilution liquid, introduced to lower head 17 via two or more nozzles 36. Nozzles 36 are typically uniformly spaced about the central discharge 18 and introduce dilution liquid, for example, filtrate from a downstream pulp washer, to dilute the slurry of material in the vicinity of outlet 18. The dilution of the slurry, or the reduction in the slurry consistency, allows the material to be more readily discharged, for example, by means of discharge device 28. However,

conventional nozzles 36 are typically located to aid discharge from outlet 18, and, the inventors believe, are therefore located too distant from the region of compression to provide any significant impact upon the flow of material in those compressed regions. The dilution introduced by nozzles 36 also typically cools the slurry which, among other things, reduces the temperature of the slurry in preparation for further treatment, for example, pulp washing.

**[0019]** As is also typical in the prior art, dilution liquid may also be introduced via nozzles 38 located in the bottom of cylindrical section 19 above the bottom head 17. The dilution introduced via nozzles 38 may also reduce the consistency of the slurry and cool the slurry prior to discharge. However, the liquid introduced via nozzles 38 may also pass upward as indicated by arrows 26 to cool or treat the slurry passing downward as indicated by arrows 24.

**[0020]** The mode of slurry flow and dilution introduction illustrated in FIGURE 1 is common to most, if not all, of the hundreds of continuous digesters in operation throughout the world. However, the inventors have discovered that this mode of operating a treatment vessel, in particular, this mode of introducing dilution liquid to the bottom head of the treatment vessel, does not promote uniform movement of slurry and thus does not promote the uniform treatment of the solid material contained in the slurry. For instance, conventional digester operation may exhibit non-uniform movement of slurry and liquid in the vicinity of bottom head 17. For example, prior art continuous digester operation may be characterized by temperature gradients about bottom head 17 and non-uniform flows in nozzles 36 and 38 (for example, as indicated by surface temperature differences of individual nozzles).

**[0021]** Though the actual cause of these temperature gradients and the consequent non-uniform flows with which the temperature gradients are associated is

unclear, the inventors theorize that the non-uniformities may be caused by the combined effects of the resistance to flow provided by the converging flow path of bottom head 17 and compression of the slurry due to the weight of the chip column above. The inventors suggest that the resistance to flow may be a function of the friction properties between the material being treated (that is, the treated wood chips) in the slurry and the internal surface of bottom head 17. For example, when the resisting force of friction exceeds the motive force of the down-flowing chip mass, the flow of slurry may decrease and the slurry may become compressed. This compression of the slurry may cause the slurry to thicken or dewater which can further increase the friction of the slurry against bottom head 17 and further exacerbate an undesirable flow condition.

**[0022]** According to one aspect of the invention, the resistance to slurry flow is reduced or minimized by introducing liquid to the slurry in the vicinity of bottom head 17, for example, in addition to the dilution introduced via nozzles 36. The inventors surmise that the diluting effect of the liquid reduces the restriction to flow by either reducing the consistency of the slurry or reducing the friction between the wall and slurry, or a combination of both. According to one aspect of the invention, dilution is introduced anywhere in bottom head 17 where regions of compression and flow resistance can hamper the flow of slurry. In another aspect of the invention, dilution is introduced at a location where the shape of head 17 imposes a change in flow path of the slurry from an essentially vertical path to a non-vertical path. In another aspect of the invention, dilution is introduced to bottom head 17 in the vicinity of the corner or knuckle of bottom head 17.

**[0023]** According to another aspect of the invention, one or more baffle plates may be introduced to the converging transition. For example, a continuous ring of one or more plates may be provided in the transition zone of the converging bottom head 17

to promote movement of slurry toward outlet 18 and minimize stagnation of slurry in the corner or "knuckle" of bottom head 17. These baffle plates, sometimes referred to as "slide plates", can be used with or without the dilution nozzles discussed above.

**[0024]** One aspect of the present invention which address this and other disadvantages of the prior art is illustrated in FIGURE 2. Though the discussion of the aspect of the invention shown in FIGURE 2 describes the present invention with respect to its application to the operation of a continuous chemical pulping digester, it will be apparent to those of skill in the art that the present invention may be applied to any vessel, in and out of the Pulp and Paper Industry, which handles solid materials or slurries of solid materials, which includes, but is not limited to, storage vessels, retention vessels, treatment vessels (for example, washing and bleaching vessels), among others.

**[0025]** FIGURE 2 illustrates a cross-section view of vessel 50 incorporating one or more aspects of the present invention. FIGURE 2 illustrates a bottom section 52 of vessel 50 that is very similar to bottom section 16 of vessel 10 shown in FIGURE 1. Vessel 50 typically includes a top section 12 as shown in FIGURE 1, but the top section of vessel 50 is omitted for clarity of illustration. The features of FIGURE 2 which are essentially identical to the features of FIGURE 1 are identified in FIGURE 2 by the same reference numbers used in FIGURE 1. Similar to vessel 10 in FIGURE 1, vessel 50 in FIGURE 2 includes a cylindrical vessel section 19, a bottom head 17, a discharge 18, and a rotating discharge device 28, and may include dilution nozzles 36 in the bottom head and dilution nozzles 38 above the bottom head.

**[0026]** According to one aspect of the invention, as shown in FIGURE 2, dilution liquid is introduced to bottom head 17 via one or more nozzles 54. Nozzles 54 are typically positioned at a radial position closer to the outside diameter of vessel 50 than

to outlet 18. For example, nozzles 54 may be positioned at a radial distance that is at least about 75% of the outer radius of vessel 50, for instance, at least about 75% of the outer radius of bottom head 17. In addition, a plurality of nozzles 54 may be uniformly located on a diameter that is at least about 75% of the outer diameter of vessel 50. In one aspect of the invention, the radial distance (or common diameter) of the position of one or more nozzles 54 is at least 90% of the outer radius (or diameter) of vessel 50 (or 90% of the outer radius of bottom head 17). Nozzles 54 may comprise conduits or pipe having nominal diameters ranging from about one-half inch to about 5 inches. In one aspect of the invention, as shown in FIGURE 2, nozzles 54 may comprise 1-inch to 2-inch pipe. In one aspect of the invention, nozzles 54 are provided to a vessel having one or more existing nozzles 36 (that is, one or "bottom dilution nozzles" as they are known in the art). When nozzles 36 are present, nozzles 54 may be positioned in bottom head 17 at a radial distance beyond nozzles 36. Also, in one aspect of the invention, when both nozzles 36 and 54 are provided, the location of nozzles 54 may be staggered, or positioned circumferentially between, nozzles 36.

**[0027]** In one aspect of the invention, at least one nozzle 54 may be positioned in bottom head 17 where the slurry within bottom head 17 undergoes increased compression. In one aspect of the invention, at least one nozzle 54 may be positioned in bottom head 17 where movement of the slurry within bottom head 17 is hindered or stagnated, for example, due to compression or frictional forces within bottom head 17. For example, in one aspect of the invention, for a flanged and dished bottom head 17 having an outer diameter of about 20 feet (that is, having an outer radius of about 10 feet), one or more nozzles 54 may be uniformly positioned at a radius of about 9 feet 6 inches.

**[0028]** In one aspect of the invention, the flow of liquid to nozzles 54 is controlled, for example, by means of one or more flow controlling devices 56. Flow

control devices 56 may be one or more valves (for example, a ball, gate, or other type valve) or other type flow control device. Flow control devices 56 may be manual or automated flow control devices, for example, hand-operated valves or automated valves having valve controllers. In another aspect of the invention, the flow of liquid to one or more nozzles 54 may be monitored by means of a flow monitoring device 58, for example, a flow meter of conventional type. According to one aspect of the invention, the flow of liquid to one or more nozzles 54 may be controlled by a single flow control device (for example, a flow control valve) for directing liquid to one or more nozzles 54. In this aspect of the invention, by controlling the rate of flow of liquid to each nozzle 54, plugging of individual nozzles 54 may be minimized or prevented. In another aspect of the invention, the flow of liquid to one or more nozzles 54 may be controlled by individual flow control device 56 associated with each of the one or more nozzles 54. In one aspect of the invention, the flow of liquid to each of the one or more nozzles 54 may be monitored and controlled by means of an automated flow control device and a flow monitoring device, for example, an automated flow control valve having a closed-loop automated valve controller which operates in response to a flow signal provided by the flow monitoring device. The control of the flow control device may also be regulated by a pressure sensor associated with the pressure in vessel 50 or to the pressure in a conduit leading to vessel 50. The flow control arrangement may include an automated controller having an algorithm for controlling the flow to one or more nozzles 54 in response to one or more operator-defined criteria, for example, liquid flow rate, difference in two liquid flow rates, production rate, slurry temperature, or vessel pressure, among other things.

**[0029]** The liquid provided to nozzles 54 may be obtained from any convenient source. For example, the liquid introduced to nozzles 54 may comprise water (essentially clean or otherwise), cooking liquor (including kraft white liquor or soda cooking liquor), spent cooking liquor, washing or bleaching filtrate, filtrate from the paper machines (for example, white water), evaporator condensate, flashed cooking

liquor condensate, or other chemicals (such as sodium hydroxide) or additives (such as anthraquinone, polysulfide, or their equivalents or derivatives) which can be used to treat the comminuted fibrous material in the slurry in addition to promoting uniform movement of the slurry.

[0030] According to another aspect of the invention, as shown in FIGURE 2 in phantom, one or more baffle plates 60 may be positioned in bottom head 17 to promote the movement of the slurry toward outlet 18. In one aspect of the invention, baffle plates (sometimes referred to as "slide plates") may comprise one or more plates assembled to provide an annular surface encircling the inside of bottom head 17. Plates 60 may be planer or flat plates, but also may comprise at least some curvature to facilitate conforming to bottom head 17 during installation. Plates 60 may also be non-planar, for example, the shape of plates 60 may be fashioned to optimize directing the slurry to outlet 18 while minimizing localized compression of the slurry adjacent to plate 60. Plates 60 may comprise materials or surfaces providing reduced friction to the slurry or material passing over them. For example, plates 60 may be steel plates, stainless steel plates (for example, 304 or 316 stainless steel plates) or other materials providing reduced friction. Plates 60 may be treated, for example, polished or coated, to reduce friction, for example, coated with a material containing a low-friction material, such as polytetrafluoroethylene (such as Dupont's Teflon® polytetrafluoroethylene or its equivalent). Plates 60 may be mounted to bottom head 17 by conventional means, for example, via welding or mechanical fastening, and may include one or more support or gusset plates (not shown) as required for proper installation and structural integrity. Plates 60 may have a thickness of between about 0.125 inches to about 1.00 inches. In one aspect of the invention, plates 60 may have a thickness of between about 0.25 and about 0.50 inches.

[0031] FIGURE 3 illustrates a detailed view of a cross-section of bottom head 17

in the vicinity of a nozzle 54 as shown in FIGURE 2. FIGURE 3 illustrates a section of cylindrical section 19, a section of bottom head 17, a representative nozzle 36, and a representative nozzle 54, according to one aspect of the invention, and baffle plate 60 (shown in phantom), according to another aspect of the invention. As shown in FIGURE 3, according to one aspect of the invention, the axis 64 of nozzle 54 may be oriented at an angle relative to the outer surface of bottom head 17 or to the axis 62 of vessel 50. In one aspect of the invention, axis 64 of one or more nozzles 54 may make an angle  $\alpha$  with axis 62 of vessel 50. In one aspect of the invention, the angle  $\alpha$  may be about 0 degrees, that is, the axis of nozzle 54 is essentially parallel to axis 62. In one aspect of the invention the angle  $\alpha$  may be greater than 0 degrees, for example, between about 5 degrees and about 90 degrees. In another aspect of the invention, the axis 64 of valve 54 may be perpendicular to the outer surface of bottom head 17.

**[0032]** According to one aspect of the invention, liquid may be introduced to bottom head 17 via one or more nozzles 58 (shown in phantom in FIGURE 3) instead of to nozzles 54. Nozzles 58 may be located in the curved section of bottom head 17 (for example, in the "knuckle" of bottom head 17). Nozzles 58 may be located with respect to the horizontal (as indicated by line 74), for example, by an angle  $\gamma$ . The angle  $\gamma$  may be an angle between about 15 degrees and about 75 degrees, and in one aspect of the invention, the angle  $\gamma$  may be between about 30 degrees and about 60 degrees.

**[0033]** As shown in FIGURE 3, baffle plate 60 may comprise a conical baffle plate and may have a first, inside diameter 66 and a second, outside diameter 68. Inside diameter 66 may be at least as great as the diameter of outlet 18, and may be greater than the diameter of the position of nozzles 36 or greater than the diameter of the position of nozzles 54. Outer diameter 68 may be about equal to the inside diameter of bottom head 17. Baffle plate 60 may also be oriented at any desired angle

of inclination. In one aspect of the invention, plate 60 is oriented at an angle  $\beta$  to the horizontal, for example, as illustrated by line 70. In one aspect of the invention, the angle  $\beta$  comprises an angle between about 15 degrees and about 75 degrees. In another aspect of the invention the angle  $\beta$  comprises an angle between about 30 degrees and about 60 degrees. For example, in the aspect of the invention shown in FIGURE 3, the angle  $\beta$  comprises an angle of about 45 degrees with the horizontal.

**[0034]** In one aspect of the invention, plates 60 may be used in conjunction with nozzles 54, but in another aspect of the invention, plates 60 may be used alone without the presence of nozzles 54. In one aspect of the invention, nozzles 54 may be used without the presence of plates 60. In one aspect of the invention, when plates 60 are used with nozzles 54, nozzles 54 may be positioned within the inside diameter 66 of plates 60. According to this aspect of the invention, nozzles 54 may introduce liquid to the slurry as the slurry leaves contact with plates 60, for example, within 6 inches of the inside diameter 66 of plates 60. In one aspect of the invention, liquid may be introduced in the vicinity of the first diameter 68 of plates 60 or in the vicinity of the second diameter 66 of plates 60 or in the vicinity of both diameters 66 and 68.

**[0035]** In another aspect of the invention, one or more nozzles 58 may extend through bottom head 17 to one or more apertures or perforations in plates 60. In one aspect of the invention, each extended nozzle provides liquid to an individual aperture or perforation in plates 60. These extended nozzles, or simply pipes or conduits, may provide dilution to the surface of 60 or to the slurry passing the surface of plate 60. The one or more apertures or perforations in plate 60 may be a plurality of circular holes or slots, for example, annular slots. In one aspect of the invention, the one or more apertures or perforations may be positioned at about the inner diameter 66 of plates 60.

**[0036]** In another aspect of the invention, some liquid may be provided to bottom

head 17 via one or more nozzles 58 positioned in bottom head 17 as a function of the angle of a line drawn tangent to bottom head 17. As shown in FIGURE 3, one or more nozzles 58 may be positioned in bottom head 17 at a position wherein a tangent line 76 (shown in phantom) forms an angle  $\varphi$  with the horizontal, for example, as indicated by line 78. In one aspect of the invention, the angle  $\varphi$  may range from about 45 degrees to about 75 degrees. In another aspect of the invention, the angle  $\varphi$  may range from about 55 degrees to about 65 degrees, for example, in FIGURE 3, the angle  $\varphi$  comprises an angle of about 60 degrees.

[0037] Pulp mill trials of one aspect of the invention as applied to continuous digesters dramatically illustrated the benefits of one aspect of the present invention compared to the prior art. The continuous digester used in the trial was one having an "extraction", or liquor removal, from a set of annular screens (or "extraction screens") positioned above the outlet head of the digester, for example, positioned in cylindrical section 19 in FIGURE 1. One indication of non-uniform movement (also known as "channeling"), and corresponding non-uniform treatment, in the outlet section of such a digester is a limitation in the flow of liquid out of the extraction screens and temperature gradients in the bottom of the digester. For example, non-uniform movement of slurry in the outlet section of a digester can result in stagnated flow in the regions near the extraction screens which can cause the extraction screens to plug with cellulose material and hinder liquid removal. In the mill trials, a digester was operated in the prior art mode with liquor introduced to the conventional side dilution nozzles (that is, nozzles 38 in FIGURES 1, and 2). Under such conventional conditions, the flow of liquid out of the extraction screen was limited to only about 40 GPM; no further flow could be obtained. In addition, marked temperature gradients were present in the outlet section of the digester, further indicating a non-uniform flow condition. However, when dilution liquid was introduced to four evenly-spaced dilution nozzles according to the present invention (that is, via four nozzles 54 shown in FIGURE 2), the operators were able to increase the extraction flow from the extraction screens to 200 GPM, that

is, a 500% increase compared to prior art operation. (The flow was limited to 200 GPM by other factors unrelated to the present invention and may have increased even further when employing one aspect of the present invention.) Using this aspect of the present invention, the operators were also able to reduce temperature gradients in the outlet zone. The increased extraction flow and reduced temperature gradients were attributed to the reduction or elimination of stagnant flow in the bottom head which resulted in a reduction or elimination of stagnant flow in the vicinity of the extraction screens, which this aspect of the invention provided.

**[0038]** Though the aspects of the invention described and illustrated with respect to FIGURES 1 through 3 may apply to digesters, for example, continuous digesters, those of skill in the art will recognize that the present invention is applicable to many different kinds of treatment vessels used in the Pulp and Paper Industry, and used outside the Pulp and Paper Industry, which handle solid materials or slurries of solid materials. For example, within the Pulp and Paper Industry, the present invention may be used in pulping vessels or reactors, washing vessels, bleaching vessels, pulp or chip storage or retention vessels or bins, among other vessels. Outside the Pulp and Paper Industry, the present invention may be used in any application which handles solid materials or slurries of solid materials, for example, in the materials handling industry, chemical industry, mining industry, food processing industry, and the like.

**[0039]** As such, the present invention, may be applied to any type of vessel under any types of temperature and pressures. For example, vessel 50 may treat or retain solid material at ambient temperature or at elevated temperature, for example, at a temperature ranging from about 10 degrees C (50 degrees F) to about 200 degrees C (392 degrees F). Similarly, vessel 50 may be pressurized or unpressurized. In one aspect of the invention, vessel 50 is operated at ambient pressure. In another aspect of the invention, vessel 50 may be operated at subatmospheric pressure or

superatmospheric pressure, for example, at a pressure between about 5 bar gage (72.5 psig) to about 15 bar gage (217.5 psig).

**[0040]** While the invention has been particularly shown and described with reference to preferred embodiment, it will be understood by those skilled in the art that various changes in form and details may be made to the invention without departing from the spirit and scope of the invention described in the following claims.

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